SPECIFICATION

METHOD FOR WATER HAMMERLESS OPENING OF FLUID PASSAGE, AND METHOD FOR SUPPLYING CHEMICAL SOLUTIONS AND DEVICE FOR WATER HAMMERLESS OPENING FOR WHICH THE METHOD IS USED

Field of the Invention

[0001] The present invention is concerned with improvements in a water hammer prevention system with which water hammer is completely prevented at the time of promptly opening of a fluid passage, and is more concretely concerned with a method for water hammerless opening of a fluid passage, a method for feeding chemical solutions, and a device for water hammerless opening for which the method is used so that the fluid passage is opened quickly and surely without the occurrence of water hammer on the upstream side of the fluid passage irrespective of the degree of the fluid pressure.

Background of the Invention

[0002] It has been widely known that when a passage through which a liquid such as water or the like passes is abruptly closed, there occurs so-called water hammer with which the pressure rises inside the passage on the upstream side of the closed point with vibrations, thus various problems such as the breakdown of devices or instruments connected to the passage being caused by said water hammer.

[0003] Thus, various techniques have been developed to prevent the occurrence of water hammer.

However, these techniques basically employ either one of the methods, that is, (1) the time for closing a fluid passage being set slightly longer, or (2) the vibrating pressure generated inside the passage being released to the outside by opening the bypass passage, or being absorbed by the accumulator separately installed. The former method is found to be time-taking for closing the fluid passage, thus resulting in failure in meeting with the need of the prompt closing of the passage, while according to the latter method, costs for the attachments become too high.

[0004] The afore-mentioned issues regarding water hammer have been discussed in the industrial fields where the fluid with a relatively large flow quantity is involved. In recent years, however, in the fields where a small flow quantity is dealt with, for example, a field where wafer cleaning in semiconductor manufacturing or chemical products manufacturing are dealt with, it has become a very important issue that water hammer is prevented at the time of urgent closure of the fluid to be supplied from the view points of improving the maintenance of facilities and the product quality, and, further, upgrading so-called throughput characteristics in the manufacturing process.

[0005] Patent Document 1: Toku-Kai-Hei No.7-190235 Public Bulletin

Patent Document 2: Toku-Kai No.2000-10602 Public Bulletin

Patent Document 3: Toku-Kai No.2002-295705 Public Bulletin

[0006] On the other hand, inventors of the present invention have developed and disclosed techniques to solve the afore-mentioned problems related to conventional techniques to prevent the occurrence of water hammer, that is, (1)

not being able to cope fully with the presence of urgency by a measure basically to set a closing time of the fluid passage slightly longer, and (2) not being able to cope fully with the rising costs of facilities to be attached by a measure basically to absorb or release the vibrating pressure, thus making it possible that a fluid passage being abruptly closed without water hammer at a low cost, quickly and surely.

Namely, said techniques allow a fluid passage to be abruptly closed without the occurrence of water hammer and in an extremely short lapse of time (for example, within 1000m sec) by performing the closure of a valve provided on the fluid passage by means of the multi-step operations. Also, said techniques determine the conditions for closing a valve to make it possible for the fluid passage to be closed without water hammer in advance by actually conducting valve closing tests so that the actuator of the valve body is operated by the electro-pneumatic conversion device in which said valve closing conditions are stored, thus water hammerless closing of the fluid passage being achieved quickly and surely.

Disclosure of the Invention

Object of the Invention

[0007] Techniques of water hammerless closing of a fluid passage previously developed by inventors of the present invention allow the fluid passage to be abruptly closed without causing water hammer quickly and surely, thus achieving excellent, practical effects.

However, in recent years, in the fields such as semiconductor

manufacturing facility industry, chemical and pharmaceutical industries and the like, there have been strongly desired that water hammer is surely prevented not only at the time when the fluid passage is abruptly closed, but also at the time when the fluid passage is abruptly opened. This means that the conventional measure of preventing water hammer at the time of abrupt closure of the fluid passage is found not to be sufficient. The reason is that when water hammer occurs at the time of opening the fluid passage, various difficulties such as moving of particles into the fluid passage and the like come up.

Due to the recent trend that the semiconductor cleaning devices and the like employ the cleaning equipment with which wafers are now treated one by one (a single wafer processing cleaner), it has become an important issue not only that quality improvements in a liquid supply system are achieved, but also that time required for each process is shortened to improve so-called throughput characteristics. Furthermore, with the afore-mentioned new treatment type semiconductor manufacturing facility, it becomes inevitable that the frequency of valves being opened and closed increases because wafers are singly treated. Therefore, stable or water hammerless valve opening and closing are needed. As such, it has become a severe requirement that the liquid supply system does not cause pressure fluctuations while wafers are processed.

[0008] It is an object of the present invention to solve the afore-mentioned problems with semiconductor manufacturing facilities, cleaning equipment and the like, and to provide a method for water hammerless opening of the fluid passage, and a method for the liquid supply and a device for water hammerless

opening for which the method is used so that the fluid supply passage is surely and abruptly opened in a state of water hammerlessness.

Means to Achieve the Object

[0009] Inventors of the present invention have come up with an idea of how to open a valve by the multi-step method in which a valve body of the valve blocking the passage is rapidly moved to the prescribed position before reaching the full opening position, and then, the valve body is moved to the full opening position after the short lapse of time, and at the same time, a number of analytical tests were conducted on the mechanism of how water hammer occurs by using said method for opening the valve. Also, with the results of the afore-mentioned tests, inventors of the present invention have learned how to prevent the occurrence of water hammer by making the stopping position of the valve body at the first step come within the specified range when the valve is opened.

[0010] The present invention has been created based on the afore-mentioned findings. The present invention as claimed in Claim 1 is fundamentally so constituted that, with the method by which the fluid passage is made open by means of the actuator operating type valve provided on the fluid passage having the nearly constant pressure inside the pipe passage, first the valve body is moved toward the direction of the valve opening by the afore-mentioned driving input to the actuator being increased or reduced to the prescribed set value, and the driving input to the actuator is held at the afore-mentioned set value for a short period of time, and then, said driving input is further increased or reduced

to make the valve in a state of full opening, thus the fluid passage being opened without water hammer.

[0011] The present invention as claimed in Claim 2 according to Claim 1 is so made that a normally closed and pneumatic pressure operating type diaphragm valve, or a normally closed and pneumatic pressure operating type diaphragm valve which is of the fixed capacity type with the inner capacity of the valve not being changed when the valve is operated, is employed for a valve.

[0012] The present invention as claimed in Claim 3 according to Claim 1 is so made that the time for the driving input to the actuator being held at the set value for a short period of time is made to be less than 1 second, and the pressure rise value of the fluid passage is made to be within 10% of the pressure value before the valve is made open.

[0013] The present invention as claimed in Claim 4 is fundamentally so constituted that it comprises a valve body, an actuator to drive the valve body, a vibration sensor removably fixed to the pipe passage on the upstream side of the valve, an electro-pneumatic conversion control device to which the valve opening/closing command signal is inputted and with which the actuator operating pressure Pa inputted to the actuator is controlled by the control signal Sc stored in the data storage part in advance, and a computation control device equipped with a comparison computation circuit to which the vibration detecting signal Pr from the afore-mentioned vibration sensor, the step pressure setting signal Ps to be supplied to the actuator, the step pressure holding time setting signal Ts, and the permissible upper limit vibration pressure setting signal Prm

are inputted, and with which the afore-mentioned vibration detecting signal Pr and the permissible upper limit vibration pressure setting signal Prm are compared, and the afore-mentioned step pressure setting signal is adjusted, thus outputting the control signal Sc consisting of the afore-mentioned holding time setting signal Ts and adjusted step pressure setting signal Ps to the data storage part of the afore-mentioned electro-pneumatic conversion control device.

[0014] The present invention as claimed in Claim 5 according to Claim 4 is so constituted that a computation control device comprises a step pressure setting circuit, a holding time setting circuit, a permissible upper limit vibration pressure setting circuit, a vibration pressure detecting circuit and a comparison computation circuit; and when the vibration detecting signal Pr exceeds the permissible upper limit vibration pressure setting signal Prm immediately after the actuator operating signal is step-changed, the step pressure setting signal Ps is adjusted toward the rising direction, and when the vibration detecting signal Pr exceeds the permissible upper limit vibration pressure setting signal Prm immediately after the actuator operating pressure is made to zero from the intermediate step operating pressure, the step pressure setting signal Ps is adjusted toward the lowering direction.

[0015] The present invention as claimed in Claim 6 according to Claim 4 is so constituted that an electro-pneumatic conversion device comprises a data storage part which stores the control signal Sc from the computation control device, a signal conversion part and an electro-pneumatic conversion part; the

actuator operating pressure control signal Se is outputted from the signal conversion part to the electro-pneumatic conversion part based on the control signal Sc' stored in the data storage part in advance with which no water hammer is caused.

[0016] The present invention as claimed in Claim 7 is fundamentally so constituted that it comprises an actuator operating type valve installed on the fluid passage, an electro-pneumatic conversion device to supply the 2-step actuator operating pressure Pa to the actuator operating type valve, a vibration sensor removably fixed to the pipe passage on the upstream side of the afore-mentioned actuator operating type valve, and a tuning box to which the vibration detecting signal Pr detected through the vibration sensor is inputted and from which the control signal Sc to control the step operating pressure Ps' of the afore-mentioned 2-step actuator operating pressure Pa is outputted to the electro-pneumatic conversion device, to output the 2-step actuator operating pressure Pa of the step operating pressure Ps', which makes the vibration detecting signal Pr nearly zero, from the electro-pneumatic conversion device by adjusting said control signal Sc.

[0017] The present invention as claimed in Claim 8 is fundamentally so constituted that, with the method for opening a fluid passage for which a vibration sensor is removably fixed on the upstream side of the actuator operating type valve installed on the fluid passage, and the vibration detecting signal Pr is inputted to the tuning box, and then, the control signal Sc from the tuning box is inputted to the electro-pneumatic conversion device, thus the

2-step actuator operating pressure Pa generated in the electro-pneumatic conversion device by the afore-mentioned control signal Sc being supplied to the actuator so that the actuator operating type valve is made open in the 2-step operation, the 2-step actuator operating pressure Pa to be supplied to the actuator and the vibration detecting signal Pr are compared for the relative relation of the two, and if the vibration is generated at the time when the first step actuator operating pressure Pa rises, the step operating pressure Ps' is lowered, and if the vibration is generated at the time when the second step actuator operating pressure Pa rises, the step operating pressure Ps' is raised, and the step operating pressure Ps' of the step operating pressure Pa to make the vibration detecting signal Pr nearly zero is determined by repeating a plural number of adjustments of raising or lowering the afore-mentioned step operating pressure Ps' so that the afore-mentioned actuator operating type valve is made open based on the data on the control signal Sc when the 2-step operating pressure Pa of the step operating pressure Ps' to make the generation of said vibration nearly zero is outputted from the electro-pneumatic conversion device.

[0018] The present invention as claimed in Claim 9 is fundamentally so constituted that, with the method for opening a fluid passage for which a vibration sensor is removably fixed on the upstream side of the actuator operating type valve installed on the fluid passage, and the vibration detecting signal Pr is inputted to the tuning box, and then, the control signal Sc from the tuning box is inputted to the electro-pneumatic conversion device, thus the 2-step actuator operating pressure Pr generated in the electro-pneumatic

conversion device by the afore-mentioned control signal Sc being supplied to the actuator so that the actuator operating type valve is made open in the 2-step operation, the 2-step actuator operating pressure Pa to be supplied to the actuator and the vibration detecting signal Pr are compared for the relative relation of the two, and if the vibration is generated at the time when the first step actuator operating pressure Pa drops, the step operating pressure Ps' is raised, and if the vibration is generated at the time when the second step actuator operating pressure Pa drops, the step operating pressure Ps' is lowered, and the step operating pressure Ps' of the step operating pressure Pa to make the vibration detecting signal Pr nearly zero is determined by repeating a plural number of adjustments of raising or lowering the afore-mentioned step operating pressure Ps' so that the afore-mentioned actuator operating type valve is made open based on the data on the control signal Sc when the 2-step operating pressure Pa of the step operating pressure Ps' to make the generation of said vibration nearly zero is outputted from the electro-pneumatic conversion device.

[0019] The present invention as claimed in Claim 10 according to Claim 8 or Claim 9 is so made that the vibration sensor and tuning box can be removed after the data on the control signal Sc at the time of outputting the 2-step operating pressure Pa with which the generation of vibration is nearly zero were inputted to the memory storage of the electro-pneumatic conversion device.

[0020] The present invention as claimed in Claim 11 according to Claim 8 or Claim 9 is so made that the vibration sensor is provided at the position on the upstream side within 1000mm from the place where the actuator operating type

valve is installed.

[0021] The present invention as claimed in Claim 12 according to Claim 8 or Claim 9 is so made that the step operating pressure holding time t of the 2-step operating pressure Pa is set at less than 1 second.

[0022] The present invention as claimed in Claim 13 is so made that, with the method with which a fluid is supplied to the fluid passage on the downstream side by opening the fluid passage by means of the actuator operating type valve installed on the fluid passage having a nearly constant internal pressure therein, a chemical solution is used for a fluid, and firstly, the valve body is moved toward the direction of the valve opening by increasing or decreasing the afore-mentioned driving input to the actuator to the prescribed set value, and the actuator driving input is held at the afore-mentioned set value for a short period of time, and then, said driving input is further increased or decreased to make the valve in a state of full opening so that water hammer does not occur at the time of the valve being opened.

[0023] The present invention as claimed in Claim 14 according to Claim 13 is so made that the time to be held at the set value for a short period of time is made to be less than 1 second, and the pressure rise value of the fluid passage is made to be within 10% of the pressure value before the valve is made open.

Effects of the Invention

[0024] With the method of the present invention, it is made possible that a fluid passage is abruptly opened in an extremely short period of time (e.g., within 300~1000m sec.) and without causing water hammer because the valve can be

opened in the manner that, in case the fluid pressure is constant, the driving force to the actuator is held at the set value, to move the valve body to the prescribed position once for a short period of time to halt, and then, the valve body is moved to the full opening position, thus making the set value for the afore-mentioned driving force the value in the appropriate range.

[0025] With the water hammerless opening device according to the present invention, it is so constituted that water hammerless valve opening is achieved by a vibration sensor 18 being removably fixed to the pipe passage L_1, the vibration detecting signal Pr detected by the vibration sensor 18 being fed back to the computation control device 16, and the actuator operating pressure to be applied to the actuator 11 of the valve body 10 through the mediation of the electro-pneumatic conversion control device 17 being controlled.

As a result, without a stroke position detecting device being installed on the valve body 10, or without the pressure detector being left attached to the pipe passage L_1, water hammerless opening can be achieved, and once the optimum conditions on water hammerless valve opening (that is, the conditions on the control of the actuator operating pressure Pa) for the subjected pipe passage L_1 is determined, the vibration sensor 18 and computation control device 16 can be removed so that they can be used for other pipe passages, thus making it extremely advantageous economically.

[0026] Furthermore, with the water hammerless opening device for the fluid passage according to the present invention, it is so made that a vibration sensor 18 is installed in the vicinity of the valve body 10 on the pipe passage under the

actual operating condition, and the valve body 10 is actually operated for opening/closing by applying the prescribed 2-step actuator operating pressure Pa to the actuator 11 of the valve body 10 from the electro-pneumatic conversion device 20 so that the optimum value of the step operating pressure Ps' of the afore-mentioned 2-step actuator operating pressure Pa is determined through the actual operation of the valve body 10, and the determined actuator operating pressure Pa is stored at the storage device of the electro-pneumatic conversion device 20.

As a result, it makes possible that the valve body 10 is abruptly opened surely and promptly without causing water hammer on the fluid passage with the actuator operating pressure Pa from the electro-pneumatic conversion device 20.

[0027] In addition, the selection and setting (tuning) of the afore-mentioned 2-step actuator operating pressure Pa can be easily performed through the actual operations of the valve body 10 over 5~6 times. Also, by applying the actuator operating pressure Pa having the appropriate step operating pressure Ps' to the actuator 11, the value in amplitude of the pressure vibration at the time of the valve body 10 being actually opened for the first time can be suppressed at the lower value, thus making it possible that the optimum value of the afore-mentioned actuator operating pressure Pa is determined accurately in advance without the pipe passage being adversely affected.

[0028] Furthermore, by utilizing a personal computer, it becomes possible that the selection and setting (tuning) of the afore-mentioned 2-step actuator

operating pressure Pa is performed extremely at ease and promptly, and also the water hammerless opening device is manufactured at lower cost.

Brief Description of Drawings

[0029] Figure 1 is a circuit diagram of the testing device used for detecting the occurrence of water hammer on the fluid passage.

Figure 2 is an explanatory drawing to illustrate an electro-pneumatic conversion device used for the testing device, wherein (a) is a basic block diagram, and (b) is a block diagram.

Figure 3 is a diagram to illustrate the relation between an input signal I (input voltage V) and an output pressure Pa (kgf/cm · G) of the electro-pneumatic conversion device 5.

Figure 4 is a diagram to illustrate, with the multi-step opening in which the internal pressure P_1 of the pipe passage 1 is made constant, a state of vibration changes in the pipe passage L_1 on the upstream side of the valve in case the supply pressure Pa to the actuator is made changed, wherein (a) shows the case where Pa is opened directly from 0kgf/cm · G to 5kgf/cm · G, and (b) shows the case where Pa is dropped from 0kgf/cm · G to 3.1kgf/cm · G and then to 0.

Figure 5 is a diagram to illustrate how the internal pressure P_1 of the pipe passage changes at the multi-step type opening (Pa=0−2.5−5kgf/cm · G) in case the tank pressure (the internal pressure P_1 of the pipe passage) is made changed, wherein (a) shows the case where the internal pressure P_1 of the tank = 0.245MPa · G, (b) P_1 = 0.255 and (c) P_1 = 0.274 respectively.

Figure 6 is an enlarged view of Figure 5(c).

Figure 7 is a diagram to illustrate the relation between the internal pressure PT of the tank and the actuator operating pressure Pa to prevent water hammer with the multi-step valve closing, wherein (a) shows the case where the internal pressure of the tank = 0.098MPaG, (b) 0.196MPaG and (c) 0.294MPaG respectively.

Figure 8 is an explanatory drawing to illustrate the relation between the actuator operating pressure Pa and the time of detecting the vibration in Figure 7.

Figure 9 is a whole block diagram of the first embodiment of the water hammerless opening device for the fluid passage according to the present invention.

Figure 10 is an explanatory drawing to illustrate the control of the actuator operating pressure Pa (Figure 10a) and one example of the occurrence of the vibration (Figure10b) with the water hammerless opening device in Figure 9.

Figure 11 is a whole system diagram of the water hammerless opening device in regard to the second embodiment according to the present invention.

Figure 12 is an overview of the PC screen display of a tuning box.

Figure 13 is a block schematic diagram of an electro-pneumatic conversion device.

Figure 14 is a flow chart of auto-tuning operations.

Figure 15 is an explanatory drawing for the relation between the driving

pressure Pa and the vibration occurred in the auto-tuning operations.

Figure 16 is a diagram to illustrate the relation between the step pressure holding time t of the driving pressure Pa in steps and the pressure rising value △P.

Figure 17 is a system diagram to illustrate the case that the chemical solution supply method according to the present invention is applied to the single wafer processing cleaner of the semiconductor manufacturing equipment.

List of Reference Characters and Numerals

[0030] PT Internal pressure of a water tank

L_1	Pipe passage on the upstream side of a valve
P_1	Internal pressure of a pipe passage
Pa	Actuator operating pressure
Pao	Air supplying pressure
△G	Valve stroke
S	Valve opening/closing command signal
1	Water tank
2	Source for pressurizing a water tank
3	Pressure sensor
4	Valve
4a	Actuator
5	Electro-pneumatic conversion device
6	Valve driving gas source
7	Signal generator

8	Storage oscilloscope
10	Valve body
11	Actuator
16	Computation control device
17	Electro-pneumatic conversion control device
18	Vibration sensor
19	Tuning box
20	Electro-pneumatic conversion device
T	Opening time detecting signal
P_1	Pressure detecting signal
PM	Permissible pressure rising value setting signal
Pr	Vibration detecting signal
Prm	Permissible upper limit vibration pressure setting signal
Ps	Step pressure setting signal
Ts	Step pressure holding time setting signal (Opening time setting signal)
Sc	Control signal
Se	Actuator operating pressure control signal
So	NO-NC switching signal for a valve
t	Step pressure holding time
Ps'	Step operating pressure
A_0	Fluid supply system
B_0	Single wafer processing cleaner

W Wafer

A・B・C・D Chemical solutions to be mixed

Practice of the Invention

[0031] In order to investigate how water hammer is caused in the liquid supply system of the semiconductor manufacturing equipment, inventors of the present invention have observed the pressure changes in the fluid flow passage at the time when the flow passage is switched from the full closing to the full opening by employing a pneumatic pressure operating diaphragm.

Figure 1 is a circuit diagram of the testing device employed for the afore-mentioned investigation. Referring to Figure 1, 1 designates a water tank, 2 a source for pressurizing the water tank, 3 a pressure sensor, 4 a valve, 5 an electro-pneumatic conversion device, 6 a valve driving gas source, 7 a signal generator and 8 a storage oscilloscope.

[0032] The afore-mentioned water tank 1 having a capacity of 30 liters is of a hermetically sealed structure and stores about 25 liters of the fluid (water of 25℃) therein.

Also, the water tank 1 is pressurized by N_2 from the pressurizing source 2, and the pressurization can be adjustable as desired within the range of 100~300KPaG.

[0033] The afore-mentioned pressure sensor 3 is capable of detecting water pressure on the upstream side of the valve 4 with high sensitivity. A diffusion semiconductor type pressure sensor was employed in the testing device.

[0034] A diaphragm type pneumatic valve is used for the afore-mentioned

valve 4, and specifications thereof are: fluid inlet pressure 0.1MPa, fluid outlet pressure 0.3MPa, fluid temperature 10~100℃, the CV value 0.27, operating air pressure 3~0.6MPa, materials of liquid-contacting parts (PTFE for the valve body and PTFE for the diaphragm), and the inside diameter of the passage 4mm.

Namely, said valve 4 is a pneumatically operating diaphragm valve which valve body is a normally-closed type synthetic resin made diaphragm. The diaphragm valve body is rested on the valve seat all the time by the elastic force of the spring (not shown in the figure) so that the valve is maintained in a closed state, while the actuator 4a is operated with the supply of the operating pneumatic pressure, thus resulting in that the diaphragm valve body is moved away from the valve seat and maintained in a state in which the valve is kept open.

Accordingly, to open said normally-closed type pneumatically operating type diaphragm valve, it is required that the operating pneumatic pressure is supplied to the actuator 4a.

According to the present invention, there is no need to say that a normally-closed type pneumatically operating diaphragm valve can be replaced by a normally-open type pneumatically operating diaphragm valve. In this case, the valve is maintained in a state of being closed by raising the operating pneumatic pressure to be supplied to the actuator 4a.

[0035] The afore-mentioned electro-pneumatic conversion device 5 is used to supply driving pressure (pneumatic pressure) corresponding to the input signal

for directing the degree of the valve opening to the actuator 4a for the valve 4. With the testing device, the electro-pneumatic conversion device 5 which is constituted as shown in Figure 2 has been employed.

Namely, when the input signal I is inputted to the control circuit A, an air supply electromagnetic valve B opens so that a part of the supply pressure C is supplied to the actuator 4a for the valve 4 as an output pressure Pa through the air supply electromagnetic valve B.

The output pressure Pa is fed back to the control circuit A through the mediation of the pressure sensor E, thus the operations for correction being effected until the output pressure Pa reaches the output pressure Pa corresponding to the input signal I. Referring to Figure 2, F designates an exhaust electromagnetic valve, G exhaust, H a power source, and J an output signal corresponding to the input signal I. Said output signal J (that is, an input signal I) is inputted to the storage oscilloscope 8 as the input voltage as described later.

[0036] Figure 3 is a diagram to illustrate the relation between the value of the input signal I (input voltage V) of the afore-mentioned electro-pneumatic conversion device 5 and the output pressure Pa. It shows that the valve 4 is held in a state of full opening with the input voltage 5V (operating air pressure P = approximately 5kgf/cm · G).

[0037] A compressor is employed for the afore-mentioned valve operating air source 6 to supply air with the prescribed pressure. And, the afore-mentioned signal generator 7 generates the input signal I and the like to the

electro-pneumatic conversion device 5 and the like so that the desired voltage output is outputted to the electro-pneumatic conversion device 5 as the input signal I.

Furthermore, the pressure detecting signal P_1 (voltage V) in the pipe passage L_1 on the upstream side from the pressure sensor 3 and the input signal I (input voltage V) to the electro-pneumatic conversion device 5 are inputted to the afore-mentioned storage oscilloscope 8, to observe and record the changes in the pressure P_1 in the pipe passage L_1, the changes in the input signal (input voltage V) and the like. The storage oscilloscope 8, which time-axis is graduated in 500m sec/1, has been employed for the testing device.

[0038] Referring to Figure 1, the internal pressure PT of the water tank 1 is held at a specified pressure of 0.172MPa・G, and the air pressure Pa of 0.490MPa・G is supplied to the actuator 4a, thus making the valve 4 to a state of full opening from a state of full closing. Here, the inside diameter of the pipe passage L_1 was 4.0mm, the length approximately 1.0m, and the flow rate Q of the water approximately 3.45 liters/min. Figure 4 shows changes in the supply air pressure to the actuator 4a for the valve 4 and in the internal pressure P_1 of the pipe passage L_1 on the upstream side observed by the storage oscilloscope.

As apparent from the afore-shown Figure 4(a), there were shown changes in the vibration output with the amplitude of approximately maximum 12V as in Figure 4(a) when the valve 4 was fully opened through the process of 0 (fully closed)→0.490MPa・G (fully opened).

[0039] On the contrary, in case the supply pressure Pa is made changed as 0

→0.29→0.490 (Figure 4(b)), there were seen nearly no changes in the vibration of the pipe passage, thus resulting in that water hammer is perfectly prevented.

[0040] Namely, it is apparent that, if the internal pressure P_1 of the pipe passage L_1 is constant, (1) the fluid passage can be opened without causing water hammer in about 500~1000m sec by opening the valve instantaneously from a state of closing to a certain degree of opening, and then making the valve to a state of full opening after a short lapse of time, and (2) water hammer cannot be prevented if the afore-mentioned initial halt position of the valve body, that is, the degree of valve opening, is either greater or smaller than a specific value.

[0041] Figure 5(a), (b), (c) show the pressure changes in the pipe passage on the upstream side of the valve 4 when the step pressure Ps is made changed from 0.245MPa・G to 0.255MPa・G to 0.274MPa・G, and the pressure Pa of the actuator is made changed as 0→0.245→0.49MPa・G, to open the valve 4 fully in 100m sec.

[0042] Figure 6 is what the afore-shown Figure 5(c) is enlarged. It becomes apparent that the vibration of the pipe passage L_1 on the upstream side can be made nearly zero by fully opening the valve 4 with the 2-step operations to raise the pressure Pa of the actuator in the order of 0→0.294→0.490MPa・G in about 1000m sec.

[0043] Figure 7(a), (b), (c) show what surveyed on the relation between the step pressure Ps and the vibration pressure in the pipe passage L_1 on the upstream side in case the internal pressure of the tank is made to be 0.098, 0.196 and 0.294MPa・G respectively. Thus, it becomes apparent that there

exists the step pressure Ps which minimizes the vibration pressure for each case. Here, a holding time of the step pressure is made to be 1000m sec.

[0044] Figure 8 is an explanatory drawing of the supply pressure Pa to the actuator 4a in the test of the afore-shown Figure 7, and shows the relation of the positioning of the step pressure Ps and the first step (point A) and the second step (point B).

[The First Embodiment of a Water Hammerless Opening Device]

[0045] Figure 9 and Figure 10 illustrate the basic block configuration of the first embodiment of a water hammerless opening device for the fluid passage according to the present invention. The device is mainly used when it is found difficult to mount a pressure detector Pc on the pipe passage L_1 on the upstream side which has been already installed, or to mount a valve stroke detector (a position detector) on the valve body 10.

[0046] Referring to Figure 9 and Figure 10, said water hammerless opening device is made by assembling a valve body 10, an actuator 11, an electro-pneumatic conversion control device 17, a computation control device 16 which makes possible the control over the step switching of the actuator operating pressure Pa, the pressure holding time Ts after having been switched and the like, and a vibration sensor 18 removably fixed to the pipe passage L_1 on the upstream side so that the conditions of opening the valve body 10 which make water hammerless opening possible are set and stored beforehand by appropriately selecting the step switching of the actuator operating pressure Pa (switching from 0 to the step pressure Ps in Figure10(a)) applied to the actuator

11 of the valve body 10 and the holding time Ts of the step pressure Ps.

[0047] Namely, with Figure 9 and Figure 10, 16 designates a computation control device, 17 an electro-pneumatic conversion control device, 18 a vibration sensor, 6 a valve driving gas source, 10 a valve body and 11 an actuator. The driving pressure Pao (approximately 0.6MPa in this embodiment) from the valve driving gas source is converted to the step operating pressure Pa as shown in Figure10(a) by the electro-pneumatic conversion control device 17, and applied to the actuator 11.

[0048] The actuator operating pressure Pa applied to the actuator 11 and its holding time Ts are controlled by the control signal Sc from the computation control device 16 determined by the operating test of opening the valve body conducted for each pipe passage L_1 on the upstream side of the valve beforehand in the manner described later. Said vibration sensor 18 and computation control device 16 are removed from the pipe passage L_1 on the upstream side upon completion of selecting the afore-mentioned control signal Sc by the operating test of opening the valve body 10.

[0049] Namely, the afore-mentioned computation control device 16 is equipped with a setting circuit 16a for the step pressure setting signal Ps, a setting circuit 16b for the pressure holding time setting signal Ts, a setting circuit 16c for the permissible upper limit vibration pressure setting signal Prm, a pipe passage vibration pressure detecting circuit 16d, a comparison computation circuit 16e and the like, and to which the vibration detecting signal Pr by changes in the internal pressure P_1 detected by the vibration sensor 18 at the time of opening

the valve body 10, the step pressure setting signal Ps, the step pressure holding time setting signal Ps, and the permissible upper limit vibration pressure setting signal Prm are inputted respectively.

[0050] And, the vibration detection signal Pr and the permissible upper limit vibration pressure setting signal Prm are compared at the comparison computation circuit 16e. When the difference is found between them, as described later, the step pressure setting signal Ps is corrected so that the control signal Sc including said corrected step pressure step pressure setting signal Ps and the holding time setting signal Ts is outputted to the data storing part 17a of the electro-pneumatic conversion control device 17.

[0051] Also, the afore-mentioned electro-pneumatic conversion control device 17 is equipped with a data storage part 17a, a signal conversion part 17b (a signal generator 7), an electro-pneumatic conversion part 17c (an electro-pneumatic conversion device 5) and the like. The actuator operating pressure Pa supplied to the actuator 11 is switched and converted in the steps as shown in Figure 10(a) by the actuator operating pressure control signal Se from the signal conversion part 17b being inputted to the electro-pneumatic conversion part 17c.

The switching signal So to correspond to the valve opening/closing command signal S and the operating situation (NO or NC) of the valve body 10 is inputted to said electro-pneumatic conversion control device 17.

[0052] Referring to Figure 9, firstly a vibration sensor 18 is fixed to the pipe passage. Next, the appropriate step pressure setting signal Ps, step pressure

holding time setting signal Ts and permissible upper limit vibration pressure setting signal Prm are inputted to the computation control device 16, and the valve body switching signal So of the electro-pneumatic conversion control device 17 and the actuator operating fluid supply pressure Pao are appropriately set.

[0053] Then, by inputting the valve opening/closing command signal, the actuator operating pressure Pa, for example, like a form of Figure 10(a), is supplied to the actuator 11 of the valve body 10.

Now, when the actuator operating pressure Pa is raised from 0 to Ps at a time t_1, the fluid passage of the valve body 1 is opened up to its mid-position, and the valve body 10 is in a state of full opening by the actuator operating pressure Ps being made Pamax at a time t_2 when, further, the set holding time elapsed.

[0054] Meantime, if the internal pressure P_1 of the pipe passage L_1 changes due to the occurrence of water hammer, the changes are detected by the vibration sensor 18 and the vibration detecting signal Pr is inputted to the computation control device 16.

In the computation control device 16, the detecting signal Pr and permissible upper limit vibration pressure setting signal Prm are compared, and when it is found that there occurs no vibration or the vibration is within tolerance at a position A_1 (time t_1), but the vibration exceeds tolerance Prm at a position A_2 (time t_2), the step pressure setting signal Ps is corrected to raise the actuator operating pressure a little so that the corrected sep pressure setting signal Ps

and holding time setting signal Ts thereof are outputted as the control signal Sc from the computation control device 16 to the electro-pneumatic conversion control device 17, and the same operating tests for opening the valve body are repeated thereafter.

[0055] Conversely, when it is found that the vibration occurred at a position A_1 (time t_1) exceeds the permissible upper limit vibration pressure setting signal Prm, the setting signal Ps is corrected to lower the afore-mentioned step pressure setting signal Ps a little, and outputted as the control signal Sc from the computation control device16 to the electro-pneumatic conversion control device 17, and the same operating tests for opening the valve body 10 are repeated thereafter.

[0056] Through repeated operating tests as stipulated in the above [0046] and [0049], the intermediate operating pressure Ps (the step pressure setting signal Ps) for the actuator 11 required for water hammerless opening of the pipe passage L_1 equipped with a vibration sensor 18 is selected for the specified step pressure holding time setting signal Ts (the valve opening time Ts). The selected control signal Sc with which the optimum step pressure setting signal Ps and holding setting time Ts for not causing water hammer are given is stored in the data storage part 17a of the electro-pneumatic conversion control device 17, and the pipe passage L_1 is opened from then on by controlling the actuator operating pressure Pa based on the stored control signal Sc.

[0057] With the embodiment in the afore-shown Figure 9 and Figure 10, it is so made that the actuator operating pressure Pa is controlled in 2 steps.

However, there is no need to say that it can be switched in 3 steps or 4 steps when necessary.

Normally, the step holding time setting signal Ts is set between 0.5~1 second. There is no need to say that the shorter said time Ts becomes, the more difficult it becomes to find the conditions for water hammerless opening.

[The Second Embodiment of a Water Hammerless Opening Device]

[0058] Figure 11 illustrates the second embodiment of the method of opening a fluid passage and the water hammerless opening device for which the method is used according to the present invention.

In Figure 11, L_1 designates a pipe passage, 10 a valve body, 11 an air actuator, 18 a vibration sensor, 19 a tuning box and 20 an electro-pneumatic conversion device. The basic configuration as a water hammerless opening device is almost the same as that of the first embodiment shown in Figure 9.

[0059] The afore-mentioned tuning box 19 is for optimizing the actuator operating pressure Pa in 2 steps supplied to the air actuator 11 by the vibration detecting signal Pr from the vibration sensor 18 mounted on the upstream side of the valve body 10 being inputted as a feedback signal, to detect the occurrence of water hammer from said feedback signal Pr and to output the control signal Sc for the actuator operating pressure to the electro-pneumatic conversion device 20. Concretely, as described later, the optimal values for the step operating pressure Ps' of the actuator operating pressure Pa and the step operating pressure holding time t in Figure 15 are computed, thus outputting the control signal Sc to the electro-pneumatic conversion device 20 to make said

actuator operating pressure Pa output from the electro-pneumatic conversion device 20 to the actuator 11.

[0060] Said tuning box 19 is equipped with a selector switch for switching the control signal Sc corresponding to the type of operation (N.O. or N.C.) of the air actuator 11 of the valve body 10.

[0061] Figure 12 shows one example of the PC screen display which forms the major part of the tuning box. The screen display is so constituted that a state of opening/closing of the valve body 10, the actuator operating pressure Pa to the air actuator 11, circumstances of the vibration of the pipe passage L_1, the step operating pressure Ps' and pipe vibration values, the condition setting for auto-tuning, the condition setting for manual opening/closing, the operation type of the valve body 10 and others can be displayed on the screen.

[0062] The signal converter and electro-pneumatic converter are combined to make the afore-mentioned electro-pneumatic conversion device 20. As shown in Figure 13, it comprises an air inlet electromagnetic valve B, an air outlet electromagnetic valve F, a pressure sensor E, a control circuit A and others. Basically, its configuration is almost the same as those shown in Figure 2(a) and (b).

[0063] Namely, the air pressure higher than 0.6MPa is supplied to the air inlet electromagnetic valve B, and the air pressure of 0~0.5MPa is outputted to the actuator 11 as the actuator operating pressure Pa.

The control circuit A of said electro-pneumatic conversion device 20 is equipped with the substrate A_1, the outside input/output interface A_0 and others.

The outside input/output interface A_0 is equipped with two connectors Ac and Ad. A power supply source (DC24 or 12V), an opening/closing signal I (voltage input or non-voltage input) and a pressure monitor (0~5DCV · 0~981KPaG) are connected to the connector Ad, while a tuning box 19 is connected to the connector Ac.

[0064] Figure 14 shows the implementation flow of the auto-tuning in said second embodiment. Figure 15 shows the relative relation between the actuator operating pressure Pa applied to the actuator 11 and the occurrence of the vibration.

As in the case of Figure 10, the actuator operating pressure in 2 steps is applied as the actuator operating pressure Pa.

[0065] Referring to Figure 14,.as shown in Figure 11, the vibration sensor 18 is fixed at a prescribed position of the pipe passage L_1 (a position on the upstream side within about 1000mm from the valve body 10, or preferably a position of 100~1000mm away to the upstream side), and a tuning box 19 and an electro-pneumatic conversion device 20 are set respectively.

Next, the valve is held in a state of full closing for about 2 seconds (step S_2) with the input (step S_1) of the auto-tuning start signal, and then thee actuator operating pressure Pa is applied in 2 steps for the control being conducted (step S_3). As described later, the holding time t of the step operating pressure Ps' has been set between 0.5~1 sec.

[0066] The vibrations caused on the pipe passage L_1 when the valve body10 is opened are detected and confirmed (step S_4) by the vibration detecting signal Pr

from the vibration sensor 18, to check to see if the vibrations are caused at the point A or at the point B (step S_5, step S_6). When it is found that the vibrations are caused at the point A, the step operating pressure Ps' of the actuator operating pressure Pa is reduced (step S_7), while when it is found that the vibrations are caused at the point B, the afore-mentioned step operating pressure Ps' is raised (step S_8).

[0067] The actuator operating pressure Pa having the optimum step operating pressure Ps' with which no vibration is caused is eventually obtained by repeating the control of the opening of the afore-mentioned valve body 10 (normally over 2 or 3 to 15 times). The valve body 10 is made open by inputting the control signal Sc to output the actuator operating pressure Pa in 2 steps, with which the vibrations are completely prevented, obtained through the auto-tuning to the electro-pneumatic conversion device 20.

[0068] The shorter the step operating pressure holding time t of the actuator operating pressure Pa in 2 steps applied at the time of the afore-mentioned auto-tuning, the better. However, with a pneumatically operating actuator 11, it is desirable that the time t is less than 1 second.

With afore-shown Figure 14 and Figure 15, the explanation is given for the case that the normally closed type pneumatically operating diaphragm valve is employed, and the valve body 10 which valve is closed is made open by supplying the actuator operating pressure Pa. However, there is no need to say that water hammerless opening can also be achieved by employing the normally open type pneumatically operating diaphragm valve and reducing the

actuator operating pressure Pa in 2 steps. In this case, it should be noted that the adjustments of the step operating pressure Pa' of the actuator operating pressure Pa are the reverse of the case of the afore-mentioned normally closed type, That is, when the vibrations are caused at the time of the actuator operating pressure Pa in the first step being reduced, the step operating pressure Pa' is raised, while when the vibrations are caused at the time of the actuator operating pressure Pa in the second step being reduced, the step operating pressure Pa' is lowered.

[0069] Figure 16 illustrates a relation between the step operating pressure holding time t and the pressure rising value $\triangle$P(MPaG) when the pneumatic pressure operating valve (19.05mm), with which the inner capacity remains unchanged at the time when the valve is opened or closed, is employed, and 3 pipe passages with the liquid line of 0.098MPa, 0.198MPa and 0.294MPa are opened with the operating pressure Pa having the actuator operating pressure Pa of 0MPaG—0.294MPaG—0.490MPaG in 2 steps. It has been known that if the step operating pressure holding time t is made to be more than1 second, the pressure rise $\triangle$P can reach nearly zero, and if t is made to be less than 0.5 second, the pressure rise $\triangle$P goes up.

[0070] Upon completion of the afore-mentioned auto-tuning, when the control signal Sc which allows the water hammerless opening of the pipe passage L_1 (that is, the control signal for outputting the actuator operating pressure in 2 steps which allows the water hammerless opening) is determined, the data of the afore-mentioned control signal Sc (that is, the operating pressure Pa) are

transmitted to the electro-pneumatic conversion device 20, to store the data separately, thus the tuning box 19 and the vibration sensor 18 being removed.

[0071] When it becomes necessary that the valve body 10 is opened urgently, the actuator operating pressure Pa in 2 steps which allows the water hammerless opening are outputted from the electro-pneumatic conversion device 20 to the actuator 11 of the valve body 10 by using the data on the afore-mentioned control signal determined through the auto-tuning beforehand.

[0072] With the embodiment in the afore-shown Figure 11, when the actuator operating pressure Pa (the step operating pressure Ps' and the holding time t thereof) is determined upon completion of the auto-tuning operation, the data on said operating pressure Pa are transmitted to the electro-pneumatic conversion device 20, thus the vibration sensor 18 and the tuning box 19 are completely removed thereafter. However, there is no need to say that the tuning box 19 is downsized so that it can be integrated with the electro-pneumatic conversion device 20.

[0073] Figure 17 is a system diagram to illustrate how the method of supplying chemical solutions according to the present invention is applied to the single wafer processing cleaner which constitutes a semiconductor manufacturing facility. With Figure 17, A_0 designates a fluid supply system, 10 a valve body installed in the fluid supply system A_0, B_0 a single wafer processing cleaner, L_0 a pipe passage, W a wafer, A mixed chemical solution (ozonized ultra-pure water · the concentration of ozone 2~3ppm), B mixed chemical solution of hydrofluoric acid, hydrogen peroxide, ultra-pure water (mixing ratio 0.03:1:2), C

mixed chemical solution of ammonium hydroxide, hydrogen peroxide, ultra-pure water (mixing ratio 0.05:1:5), and D ultra-pure water. The fluid supply system A_0 in Figure 17 is constituted in the form like, for example, the afore-shown Figure 1, Figure 9 or Figure 11. It is so constituted that firstly the valve of the valve body 10 is moved in the direction of the valve opening through the mediation of the actuator (not illustrated) by a given degree, and next it is held as it is for a short period of time, and then the valve is moved to the position of full opening, thus the valve body 10 is fully opened.

[0074] The constitution and action of the fluid supply system A_0 are exactly the same as those in the afore-shown Figure1, Figure 9 or Figure 11. Therefore, the explanation is omitted herewith.

The cleaning process of a wafer W is that firstly cleaning is performed with the mixed chemical solution A, and next the mixed chemical solution B is supplied, and then the mixed chemical solution C and D are supplied in turn by the valve body 10 being switched through the mediation of the actuator.

[0075] At the time of supplying the chemical solution A, B, C and D, it is desirable that the pressure rise value in the pipe passage L_1 occurred when the valve body 10 is opened is kept within 10% of the pressure value before the valve is opened. In order that the pressure rise value is kept within the afore-mentioned 10%, some adjustments are made for the driving input value to the afore-mentioned actuator and also for the holding time thereof. The pressure rise value in the pipe passage L_0 can be kept within 10% of the steady state value by making the pressure rise value in the pipe passage L_1 within 10%.

Furthermore, with the embodiment, the explanation is given only for the upper limit of the pressure rise value at the time of the start of supplying mixed chemical solution A, B, C and D (or at the time of the valve being opened). However, there is no need to say that there exists the upper limit for the pressure rise value of the pipe passage L_1 at the time of the halt of supplying mixed chemical solution A, B, C and D (or at the time of the valve being closed). Each valve body 10 is operated for closing so that the afore-mentioned pressure rise value is kept within the set value.

<u>Feasibility of Industrial Use</u>

[0076] The present invention is applicable not only to the supply pipes for water, steam and the like used in industries, but also to the supply pipes for household water/hot water. It is also applicable to the supply pipes for fluids (gases and liquids) used in the semiconductor manufacturing plants, chemical plants and the like. The present invention is particularly suited for applying to chambers , wafer cleaning devices or various types of etching devices used for semiconductor manufacturing.